A simulation training evaluation method for distribution network fault based on radar chart

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Abstract. In order to solve the problem of automatic evaluation of dispatcher fault simulation training in distribution network, a simulation training evaluation method based on radar chart for distribution network fault is proposed. The fault handling information matrix is established to record the dispatcher fault handling operation sequence and operation information. The four situations of the dispatcher fault isolation operation are analyzed. The fault handling anti-misoperation rule set is established to describe the rules prohibiting dispatcher operation. Based on the idea of artificial intelligence reasoning, the feasibility of dispatcher fault handling is described by the feasibility index. The relevant factors and evaluation methods are discussed from the three aspects of the fault handling result feasibility, the anti-misoperation correctness and the operation process conciseness. The detailed calculation formula is given. Combining the independence and correlation between the three evaluation angles, a comprehensive evaluation method of distribution network fault simulation training based on radar chart is proposed. The method can comprehensively reflect the fault handling process of dispatchers, and comprehensively evaluate the fault handling process from various angles, which has good practical value.

1 Introduction

With economic development, people's demand for reliability of power supply continues to increase. In order to ensure the safety, economy and reliability of the power supply quality, higher requirements are set for the professional level of the distribution network dispatching operators [1-3].

Dispatcher simulation training is an important means of daily training and accident inversion for dispatchers [4-7]. However, it is difficult for the dispatcher simulation training to reasonably evaluate the training process and the business level of the dispatcher. At present, the dispatcher simulation training system mainly includes the substation simulation training system and the power network simulation training system [8-14]. The scoring methods mainly include traditional addition and subtraction, manual intervention, artificial intelligence matching, etc..

The simulation training system of distribution network dispatching includes two cases: normal simulation training and fault simulation training. The fault simulation training is to simulate the real-time operation status of the distribution network when the fault occurs, including the protection of alarm matters, switching action items, terminal fault alarm signals, remote signal variation, telemetry mutation and power flow distribution etc.. According to the complex and changeable information, the dispatcher can accurately determine the interval of the fault, and quickly operate the corresponding equipment isolation fault, at the same time, the relevant load that is affected by the fault will be restored to power supply. Although the frequency of occurrence of fault in distribution network is not high, but the effect is significant, although the feeder automation system can automatically isolate the fault, but the fault isolation and recovery as the basic scheduling dispatcher, has been the foundation and key distribution network simulation training.

There are few researches on the evaluation of distribution network fault simulation training. The reference [9] proposed a man-machine combined intelligent evaluation method of substation simulation. This method has great improvement in fault-tolerant case, but requires human intervention to correct the result. The reference [10] proposed a substation simulation training method based on the combination of expert system and weight function. This method introduced expert mechanism and weighting function, but did not describe fault tolerance and fuzziness of dispatcher operation. The reference [11-12] proposed a three-dimensional scene-based distribution network training simulation system, but none of the dispatcher training evaluation method was described. The reference [13] proposed a method of transformer substation operation training evaluation based on the principle of maximum matching. This method evaluated dispatchers strictly in accordance with operating procedures but did not describe the dispatcher's incomplete error operation. The reference [14] proposed a two-level evaluation method which used fuzzy comprehensive evaluation method to evaluate dispatcher's training situation synthetically. This method has more considerations on the dispatcher's rating factors, but the model is more complex and the evaluation result is affected by the weight coefficient, and it does not describe the dispatcher's incomplete error operation.

In summary, in order to make dispatcher daily training and accident inversion work effectively guide and ensure the distribution network safe, economical, efficient and reliable operation. It is of great significance to study a simulation training evaluation method for distribution network fault, which can tolerate dispatcher isolation and transfer to non-standard operation, and can effectively reflect dispatcher training operation and business level.

Based on the characteristics of the simulation training of distribution network fault, this paper presents a comprehensive evaluation method of distribution network fault simulation based on radar chart from the three dimensions of the fault handling result feasibility, the anti-misoperation correctness and the operation process conciseness.

2 Establishment of distribution network fault simulation training model

2.1 Fault handling information matrix model

The distribution network dispatching simulation training system includes two kinds of situations: normal simulation training and fault simulation training, in which fault simulation training has been the focus of dispatcher simulation training.

The key factors to evaluate the fault handling level of dispatchers can be generally summarized into three aspects. The first aspect is the feasibility of fault handling, that is, the smaller the fault isolation range is, the smaller the outage range will be affected by the fault, and the less the loss of electricity, the higher the level of fault handling. The second aspect is the correctness of anti-misoperation, that is, the dispatcher fault handling process must meet the anti-misuse rules to prevent further expansion of the fault range due to misoperation. The third aspect is the conciseness of the operation process, that is, the more concise the dispatcher's fault handling process is, the shorter the fault handling time is, and the higher the fault handling level is.

The fault handling information matrix (*FHIM*) is set up to describe the operation sequence and operation information of the equipment in the process of the dispatcher's fault treatment. The details are as follows:

$$FHIM = \begin{bmatrix} ft_{11} & ft_{12} & ft_{13} & ft_{14} & ft_{15} & ft_{16} & ft_{17} \\ ft_{21} & ft_{22} & ft_{23} & ft_{24} & ft_{25} & ft_{26} & ft_{27} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ ft_{m1} & ft_{m2} & ft_{m3} & ft_{m4} & ft_{m5} & ft_{m6} & ft_{m6} \end{bmatrix} \quad (1)$$

Wherein, the first column is the name of the operating device. The second column is the device operating status, 1 for closing, 0 for opening. The third column is the device operating time interval, which is determined by the time difference between this operation and the next operation, and the unit is second. The fourth column is the common load number of the power outages and transmission, including the common load number of the closing power supply and the ordinary load of the switching power supply, in which the ordinary load of the transmission is expressed as positive number, and the common load of the power outages is expressed as negative numbers. The fifth column is the number of important loads of power outages and transmission, in which the number of power transmission important loads is expressed as positive numbers, and the number of power outages important loads is expressed as negative numbers. The sixth column is the load of power outages and transmission, in which the load of power transmission is expressed as positive number, and the load of power outages is expressed as negative number. The seventh column is the feeder ID of the equipment, and the loop-switch belongs to the two feeder lines associated with it. *m* is the dispatcher fault handling steps.

2.2 Fault isolation range analysis

When the fault occurs, the fault area must be determined first, and then the fault area is isolated. However, during actual training, the actual fault isolation range of the dispatcher is not necessarily the same as the standard fault isolation range set by the trainer. As shown in Fig.1, there are four cases of fault isolation, in which S1 and S2 are substation outlet switches, A~J is sectionalizer switch, and K is loop-switch. Area CD is the fault point. There are four cases in the process of isolating fault: inclusion isolation, upstream isolation, downstream isolation and branch isolation.

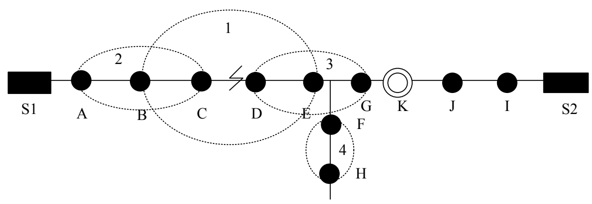

Figure 1. Four cases of fault isolation.

The so-called inclusion isolation means that the dispatcher's actual fault isolation range includes the standard fault isolation range, as shown by the ring 1 in Fig.1. It can isolate the fault correctly, and will not cause the line to lose power again when the fault is isolated and transferred to the load. This dispatcher isolation and load transfer operations are feasible.

The so-called upstream isolation means that the actual fault isolation range of the dispatcher is in the upstream of the standard fault isolation range, but there is no intersection relationship between them, as shown by the ring 2 in Fig.1. It can correctly isolate the upstream fault range and fail to isolate the downstream fault region. In the process of load transfer, it leads to the feeder voltage loss on the other side of the loop-switch. This isolation operation of the dispatcher is partially feasible without causing the side line loss of power.

The so-called downstream isolation means that the actual fault isolation range of the dispatcher is in the downstream of the standard fault isolation range, but there is no intersection relationship between them, as shown by the ring 3 in Fig.1. It can correctly isolate the downstream fault area and fails to isolate the upstream fault region, and it will cause the substation outlet switch to trip again during load transfer. The isolation operation of the dispatcher is partially feasible without causing the trip of the outlet switch again.

The so-called branch isolation means that the actual fault isolation range of the dispatcher is on the branch path, and has nothing to do with the standard fault isolation range, as shown by the ring 4 in Fig.1. It can not isolate fault area completely. In the process of load transfer, it will cause the substation outlet switch to trip again, and lead to feeder power loss on the other side of the loop-switch. This isolation operation is completely infeasible for dispatchers.

2.3 Anti-misoperation rules set

Dispatchers in the process of equipment operation should strictly abide by the anti-misoperation rules. The wrong operation sequence and operation method will lead to heavy equipment overload and reduce the service life of equipment. Seriously, they will lead to arc short circuit and line trip seriously endanger personal safety.

The anti-misoperation lock operation rules table (*ALRT*) is established to record the rules prohibiting dispatcher operation. The details are as follows:

$$ALRT = [al_1, al_2, ar_3, al_4, al_5, al_6, al_7, al_8] \quad (2)$$

Wherein, the al_1 indicates that the disconnector is closed or opened when the feeder has power. The al_2 indicates that the grounding switch is closed when the feeder is energized. The al_3 indicates that the operation causes the feeder current to cross the load limit. The al_4 indicates that the operation causes the feeder voltage to cross the limit. The al_5 indicates that the feeder is powered on while the inspection card is being hung up. The al_6 indicates that the feeder is powered off while the security card is being hung up. The al_7 indicates that the feeder is powered on while the grounding card is being hung up. The al_8 indicates that the operation causes the feeder to loop for a long time.

3 A fault simulation training evaluation method based on radar chart

The simulation training evaluation of distribution network is mainly to realize the evaluation of the results of the fault handling and the feasibility of the treatment process. It is a problem that has a close connection with people's subjective consciousness. Based on artificial intelligence, simulating human subjective consciousness is one of the methods to solve the problem.

3.1 Fault handling result feasibility evaluation

According to the fault handling information matrix and fault isolation range described in Section 2, the factors related to the fault handling result are the range of isolation, the number of critical users losing power, the number of general users losing power, the power loss load and so on. The latter three factors are the concrete manifestation of the former factor. Therefore, the fault handling result feasibility evaluation index (*FHRF*) is set up to evaluate the fault handling results from the three aspects of the number of critical users losing power, the number of general users losing power, and the power loss load. The details are as follows:

$$\begin{cases} FHRF = \alpha_1 \cdot CLLE + \alpha_2 \cdot GLLE + \alpha_3 \cdot LLE \\ \alpha_1 + \alpha_2 + \alpha_3 = 1, \alpha_1 \geq \alpha_2 \geq \alpha_3 > 0 \end{cases} \quad (3)$$

Wherein, the *CLLE* is a critical load power loss evaluation index, described as:

$$CLLE = e^{-|AC - \sum_{i=1}^{n} ft_{i5} - cl|} \quad (4)$$

The *AC* is the number of critical loads contained in the faulty feeder, and the *cl* is the standard value of the number of critical users losing power set by the trainer.

The *GLLE* is a general load power loss evaluation index, described as:

$$GLLE = \begin{cases} \dfrac{\min(AG - \sum_{i=1}^{n} ft_{i4}, gl)}{\max(AG - \sum_{i=1}^{n} ft_{i4}, gl)} & AG - \sum_{i=1}^{n} ft_{i4} \neq 0 and gl \neq 0 \\ e^{-\max(AG - ft_{i4}, gl)} & AG - \sum_{i=1}^{n} ft_{i4} = 0 or gl = 0 \end{cases} \quad (5)$$

Where, the *AG* is the total number of general loads contained in the feeder and the *gl* is the standard value of the number of general load power loss set by the trainer. The i (i= 1, 2, …, n) is the number of operation rows for the fault feeder in the *FHIM*.

The *LLE* is a power loss load evaluation index, described as:

$$LLE = \begin{cases} \dfrac{\min(AL - \sum_{i=1}^{n} ft_{i6}, ll)}{1/2 \times (AL - \sum_{i=1}^{n} ft_{i6} + ll)} & AL - \sum_{i=1}^{n} ft_{i6} \neq 0 and \ ll \neq 0 \\ e^{-\max(AL - \sum_{i=1}^{n} ft_{i6}, ll)} & AL - \sum_{i=1}^{n} ft_{i6} = 0 or \ ll = 0 \end{cases} \quad (6)$$

Where, the *AL* is the load of the fault feeder, and the *ll* is the standard value of the fault handling power loss load set by the trainer. The α_1 is a critical load weighting factor for power loss, the α_2 is a general load weighting factor for power loss, and the α_3 is the weight factor of power loss load. According to the distribution network dispatching operation experience and dispatching expert evaluation, the range of α_1 is [0.45, 0.55], the general value is 0.5; the range of α_2 is [0.25, 0.35], the general value is 0.3; the range of α_3 is [0.15, 0.25], the general value is 0.2.

3.2 Anti-misoperation correctness evaluation

Based on the *ALRT*, anti-misoperation checking is performed for each step in the *FHIM*. If the operation steps violate any one of the *ALRT*, this step operation violates the anti-misoperation lock criterion, and the accumulated value is *Anum*. The anti-misoperation correctness evaluation index (*AMCE*) is established to prevent the misoperation of dispatcher fault handling. The details are as follows:

$$\begin{cases} AMCE = \alpha_4 \cdot \dfrac{n - Anum}{n} + \alpha_5 \cdot e^{-Anum} \\ \alpha_4 + \alpha_5 = 1, \alpha_4 \geq \alpha_5 \geq 0 \end{cases} \tag{7}$$

Wherein, the α_4 is the correct step weight factor for anti-misoperation, and the α_5 is the error step weight factor for anti-misoperation. According to the distribution network dispatching operation experience and dispatching expert evaluation, the range of α_4 is [0.5, 1], the general value is 0.6; the range of α_5 is [0, 0.5], the general value is 0.4.

3.3 Operation process conciseness evaluation

The fault handling time evaluation index (*FHTE*) is established to evaluate the simplicity of the dispatcher fault operation, which is specifically as follows:

$$\begin{cases} FHTE = \alpha_6 \cdot \dfrac{n - Bnum}{n} + \alpha_7 \cdot e^{-Bnum} + \alpha_8 \cdot e^{\lambda} \\ \alpha_6 + \alpha_7 + \alpha_8 = 1, \alpha_6 \geq \alpha_7 \geq \alpha_8 > 0 \end{cases} \tag{8}$$

$$\begin{cases} \lambda = \dfrac{-\sum_{i=1}^{n} ft_{i3}}{LTime}, (\sum_{i=1}^{n} ft_{i3} > LTime) \\ \lambda = 0, (\sum_{i=1}^{n} ft_{i3} \leq LTime) \end{cases} \tag{9}$$

Wherein, the *Bnum* is the number of steps in violation of the single step operation limit (*STime*). The *LTime* is the fault handling total time set by the trainer, and the unit is seconds. The α_6 is a help-increase weight factor, the α_7 is an attenuation weight factor, and the α_8 is a total time weight factor. According to the distribution network dispatching operation experience and dispatching expert evaluation, the range of α_6 is [0.45, 0.65], the general value is 0.5; the range of α_7 is [0.25, 0.45], the general value is 0.3; the range of α_8 is [0.15, 0.35], the general value is 0.2.

3.4 Comprehensive evaluation based on radar chart

As shown in Fig.2, the concentric circles A1~A4 represent the perfect boundary (evaluation as 1), the excellent boundary (evaluation as 0.9), the good boundary (evaluation as 0.8), and the passing boundary (evaluation as 0.6) respectively. The X-axis, Y-axis and Z-axis respectively show the result evaluation, anti-misoperation evaluation and process evaluation, and x0, y0, z0 is the full score, which is 1. The difference between the axes is 120 degrees, the O is concentric circles, and the concentric circle A1 radius is R. The x, y, z respectively represent the mapping coordinate positions of the real-time evaluation situations of *FHRF*, *AMCE* and *FHTE* in the X-axis, Y-axis and Z-axis coordinates. The details are as follows:

$$\begin{cases} x = FHRF \cdot R \\ y = AMCE \cdot R \\ z = FHTE \cdot R \end{cases} \tag{10}$$

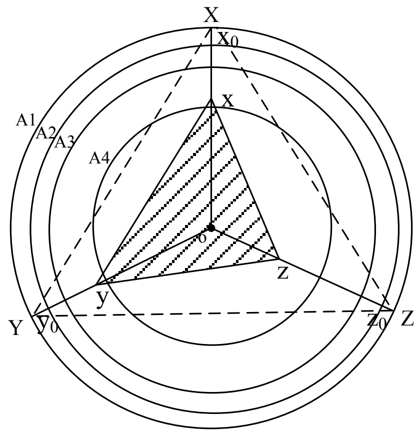

Figure 2. Comprehensive evaluation radar chart.

The comprehensive evaluation index of distribution network fault simulation training is described by the ratio of triangle xyz area and triangle $x_o y_o z_o$ area:

$$FHCE = (xy + xz + yz)/3 \tag{11}$$

4 Case Analysis

As shown in Fig. 3, the distribution network, F1-F6 represents 6 feeders, and S1-S6 is the power outlet switch of six feeders. The 11-66 solid point is the closing sectionalizer switch and the 151-562 hollow point is the split loop-switch. The x1/x2/x3 respectively represent the general load / critical load / total area load (A) contained in the minimum distribution area. If the Fault1, Fault2 and Fault3 faults occur, the operation process of the dispatcher is shown in Table 1, and the weight parameter adopts the default value described in Section 3. The other parameters, such as Table 2, are described in Section 3, and the evaluation results of each fault are shown in Table 3.

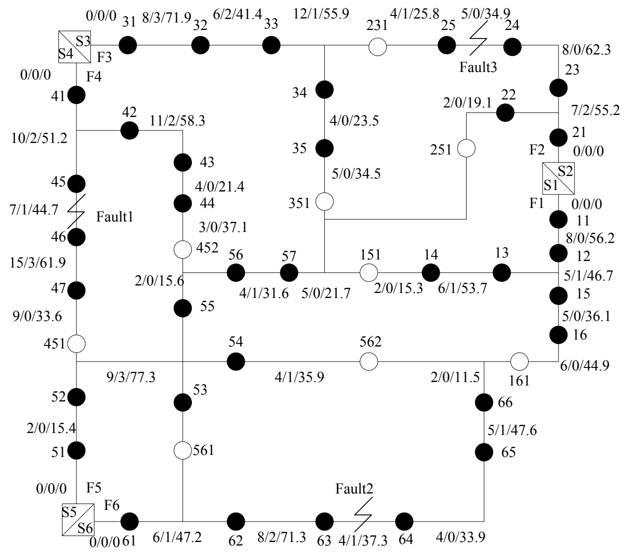

Figure 3. Typical distribution network diagram.

Table. 1 Dispatcher fault handling procedures table

Step	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Equ	41	42	46	S4	452	451	63	S6	64	161	23	24	S2	231
State	0	0	0	1	1	1	0	1	0	1	0	0	1	1
Time	12	18	20	10	15	12	25	14	18	19	20	16	15	16
Feeder	F4	F4	F4	F4	F4,F5	F4,F5	F6	F6	F6	F6,F1	F2	F2	F2	F2,F3

Table. 2 Fault handling important parameter table

Para	gl_1	gl_2	gl_3	cl_1	cl_2	cl_3	ll_1	ll_2	ll_3	*STime*	*LTime*
Val	7	4	5	1	1	0	44.7	37.3	39.4	20	80

Table. 3 Dispatcher fault handling evaluation table

Fault	***CLLE***	***GLLE***	***LLE***	***FHRF***	***AMCE***	***FHTE***	***FHCE***
Fault1	0.135	0.412	0.636	0.318	1	1	0.546
Fault2	1	1	1	1	1	0.685	0.79
Fault3	0.001	0.104	0.1	0.032	1	1	0.367

The average of the single fault evaluation results in Table 3 can be obtained as 0.568 for the three fault treatments. If using the percentile evaluation, the dispatcher fault handling result is 56.8 points.

5 Conclusion

The fault handling information matrix is established to record the dispatcher fault handling operation sequence and operation information. The four situations of the dispatcher fault isolation operation are analyzed. The fault handling anti-misoperation rule set is established to describe the rules prohibiting dispatcher operation.

Based on the idea of artificial intelligence reasoning, the feasibility of dispatcher fault handling is described by the feasibility index. The relevant factors and evaluation methods are discussed from the three aspects of the fault handling result feasibility, the anti-misoperation correctness and the operation process conciseness. A comprehensive evaluation method of distribution network fault simulation training based on radar chart is proposed. The method can comprehensively reflect the fault handling process of dispatchers, and comprehensively evaluate the fault handling process from various angles, which has good practical value.

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